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(54) **LINEAR HYDRAULIC PUMP AND ITS APPLICATION IN WELL PRESSURE CONTROL**

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F04B 49/08	(2006.01)
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E21B 43/118	(2006.01)

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(58) **Field of Classification Search**

CPC E21B 21/08; E21B 43/18; E21B 43/20; E21B 21/106; E21B 21/00; F04B 9/105; F04B 47/04

See application file for complete search history.

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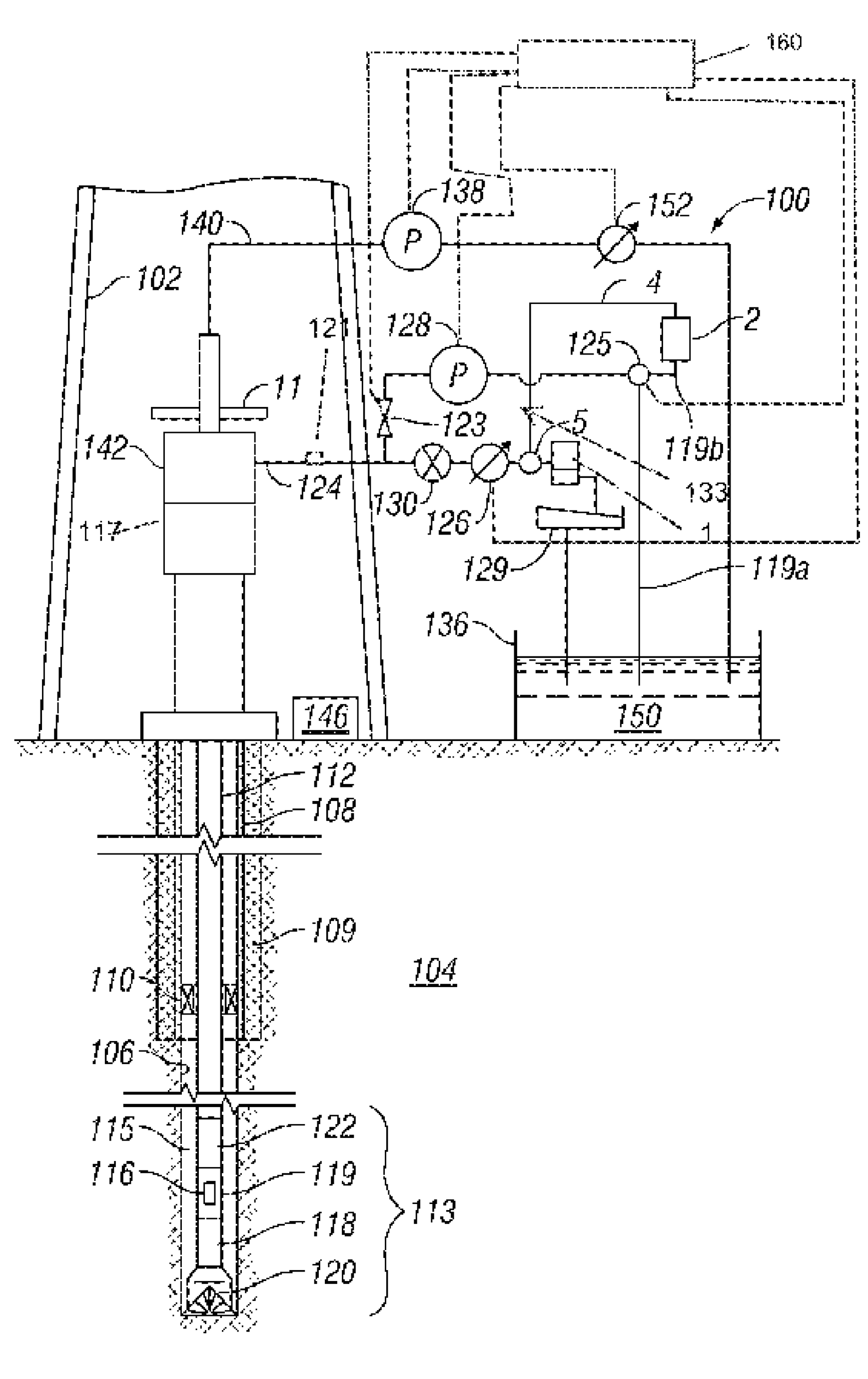
(57) **ABSTRACT**

An apparatus includes a linear motor and a fluid pump functionally connected to the linear motor. A fluid inlet of the fluid pump is in fluid communication with a fluid source. A fluid outlet of the fluid pump in fluid communication with a well. A pressure sensor is in fluid communication with the well. A controller is functionally coupled to the linear motor and the pressure sensor, wherein the controller is configured to operate the fluid pump to maintain a selected pressure in the well.

19 Claims, 2 Drawing Sheets



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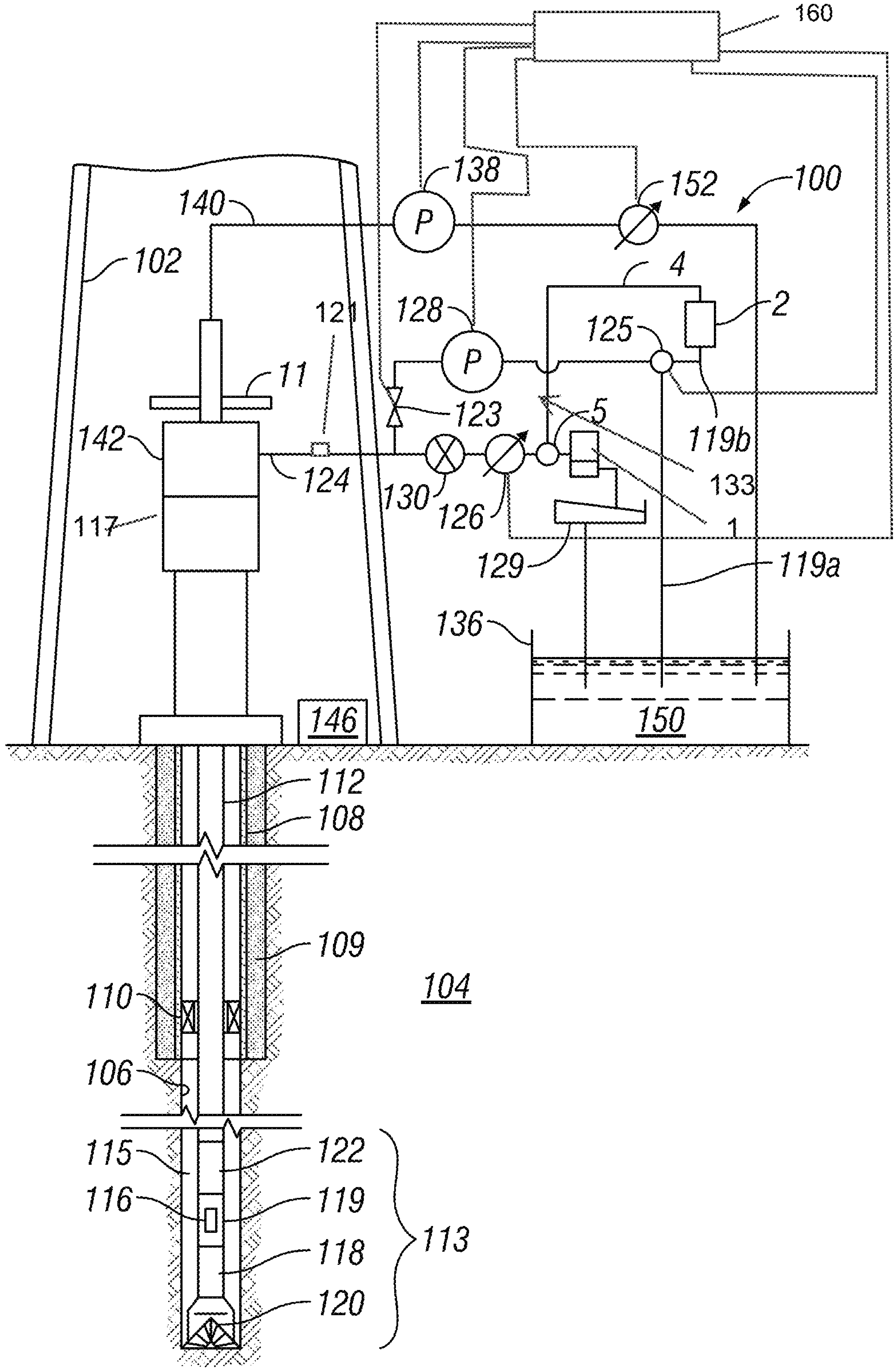
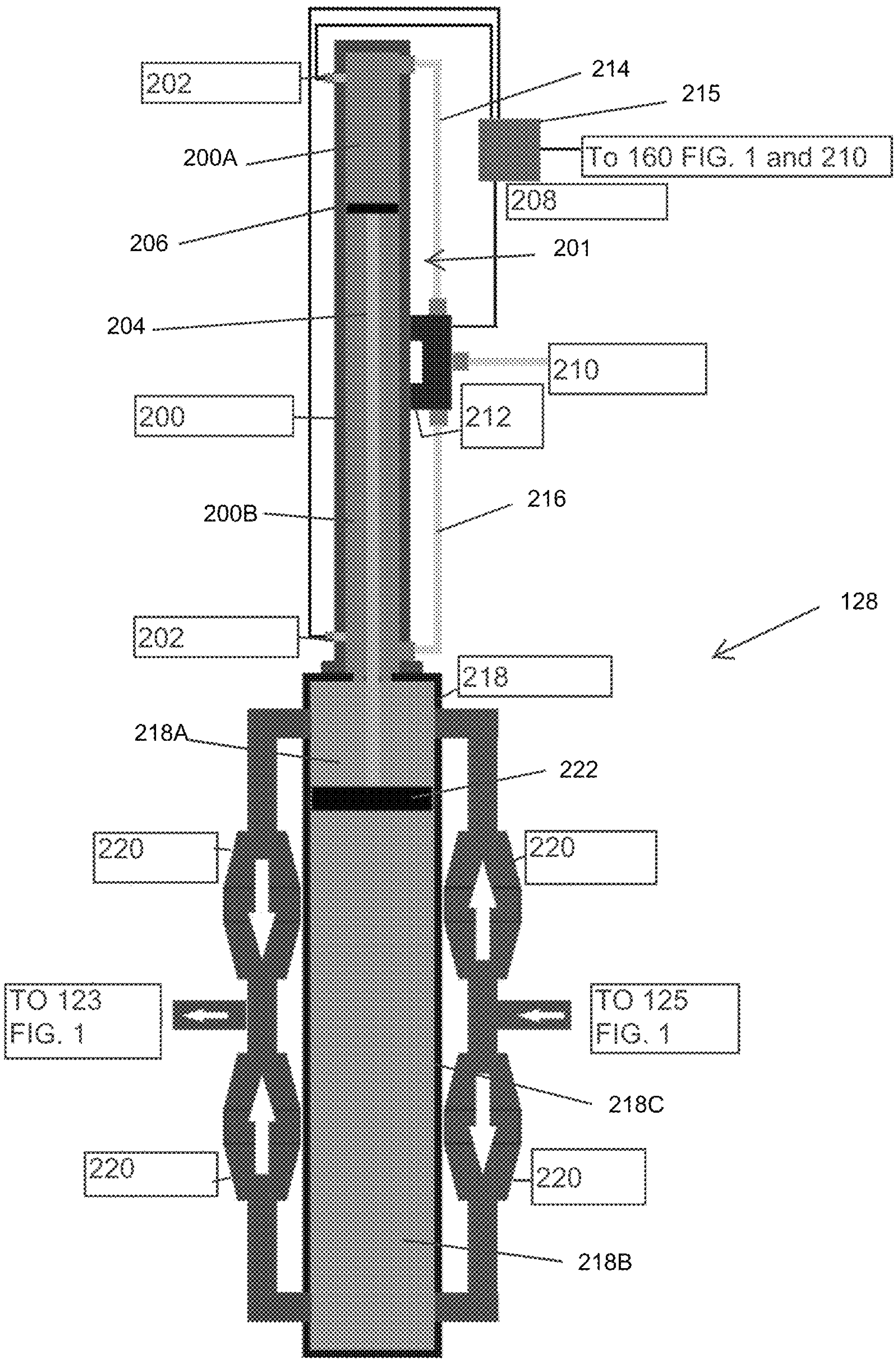

160
138
152
100
140
102
4
2
121
128
125
11
123
5
142
119b
124
133
130
126
117
1
129
119a
136
146
150
112
108
109
104
110
106
115
122
116
119
118
113
120

FIG. 1



202
214
215
To 160 FIG. 1 and 210
200A
208
206
201
204
210
200
212
200B
216
128
202
218
218A
222
220
220
TO 123
FIG. 1
TO 125
FIG. 1
218C
220
220
218B

FIG. 2

LINEAR HYDRAULIC PUMP AND ITS APPLICATION IN WELL PRESSURE CONTROL

BACKGROUND

This disclosure relates to the field of well drilling. More specifically, the disclosure relates to pumps used to maintain fluid pressure in a well during drilling operations.

U.S. Pat. No. 6,904,981 issued to van Riet describes a well pressure control system that may be used in the construction of subsurface wells. The function of the well pressure control system disclosed in the van Riet '981 patent is to maintain fluid pressure in the well higher than the hydrostatic pressure exerted by a column of fluid of a selected density at any true vertical depth in the well. Such fluid pressure is maintained by a controllable orifice choke disposed in a fluid outlet or discharge conduit from the well, where the well is closed to fluid flow other than through a drill string disposed in the well and the fluid outlet or discharge conduit. The controllable orifice choke provides a backpressure to the well resulting from restriction of fluid flow out of the well when fluid is pumped into the well through the drill string. During times when fluid is not pumped into the drill string, a backpressure pump or flow diverted from drilling rig mud pumps to the fluid outlet or fluid discharge conduit may be used to maintain a selected backpressure, and consequent selected fluid pressure in the well. Maintaining fluid pressure may require pumping additional fluid into the well using a backpressure pump or diverted flow from the drilling rig mud pumps in particular during "tripping" operations, where the drill string is withdrawn from the well. Withdrawal of the drill string from the well reduces the amount of well fluid displaced by the drill string, thus enabling the well fluid pressure to decrease; thus additional fluid may be pumped into the well to maintain the fluid pressure. Separate backpressure pumps may be preferable in some circumstances because they may be more accurately controlled than the drilling rig mud pumps. There is a need for improved backpressure pumps to enable more precise well pressure control.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows an example embodiment of a well drilling system that may be used with various implementations of a pump according to the present disclosure.

FIG. **2** shows a schematic diagram of one example embodiment of a pump according to the present disclosure.

DETAILED DESCRIPTION

FIG. **1** shows a well drilling system **100**, which may be a land-based drilling system or a marine drilling system having a well pressure control system known as "a dynamic annular pressure control" (DAPC) system that may have a pump in accordance with the present disclosure. The example embodiment of the well drilling system **100** is shown including a drilling rig **102** placed on the land surface **146** that is used to support drilling operations. Some of the components used on the drilling rig **102**, such as a kelly or top drive, power tongs, slips, draw works and other equipment are not shown separately in the figures for clarity of the illustration. The drilling rig **102** is used to support a drill string **112** used for drilling a well **106** through subsurface formations such as that shown by reference numeral **104**. As shown in FIG. **1** the well **106** has already been partially drilled, and a protective pipe or casing **108** set and cemented **109** into place in part of the drilled portion of the well **106**. In the present embodiment, a casing shutoff mechanism or downhole deployment valve **110** may be installed in the protective pipe or casing **108** to selectively hydraulically isolate an annulus **115** between the drill string **112** and the protective pipe or casing **108** and effectively act as a valve to stop flow of fluid from the open hole section of the well **106** (the portion of the well **106** below the bottom of the protective pipe or casing **108**) when a drill bit **120** at the bottom of the drill string **112** is located above the downhole deployment valve **110**.

The drill string **112** supports a bottom hole assembly ("BHA") **113** that may include the drill bit **120**, a mud motor **118**, a measurement-while-drilling and logging-while-drilling (MWD/LWD) sensor assembly **119** that in some embodiments includes a pressure transducer **116** to measure the fluid pressure in the annulus **115**. The drill string **112** may include a check valve (not shown) to prevent backflow of fluid from the annulus **115** into the interior of the drill string **112**. The MWD/LWD sensor assembly **119** may include a telemetry package **122** that is used to transmit pressure data as measured by the pressure transducer **116**, data from the MWD/LWD sensor assembly **119**, as well as drilling information to be received at the Earth's surface. Such transmission may be performed by a fluid flow modulator (not shown separately) controlled by the MWD/LWD sensor assembly **119** so as to generate changes in flow rate and/or pressure of fluid (explained below) pumped through the drill string **112**. Such changed maybe detected at the surface and decoded into measurements made by the various sensors disposed in the drill string **112**. While FIG. **1** is directed to a telemetry package **122** having a fluid flow modulation telemetry system, it will be appreciated that other telemetry systems, such as radio frequency (RF), electromagnetic (EM) or drill string transmission systems may be used in other embodiments.

The drilling process uses a fluid, which may be a fluid suspension referred to as "drilling mud" that may be stored at the surface in a reservoir **136**. The reservoir **136** is in fluid communications with one or more rig mud pumps **138** which pump the drilling mud **150** through a conduit **140**. The conduit **140** is connected to the uppermost segment or "joint" of the drill string **112** that passes through a rotating control device **142** such as a rotating diverter, rotating control head or rotating blowout preventer ("BOP"). The rotating control device urges seals (not shown separately) for example, spherically shaped elastomeric sealing elements, to rotate upwardly, closing around the drill string **112** and isolating the fluid pressure in the annulus **115**, but still enabling rotation of the drill string **112**. Commercially available rotating BOPs, such as those manufactured by National Oilwell Varco, 10000 Richmond Avenue, Houston, Tex. 77042 are capable of isolating pressure in the annulus **115** up to 10,000 psi (68947.6 kPa).

The drilling mud **150** is pumped down through an interior passage in the drill string **112** and the BHA **113** and exits through nozzles or jets in the drill bit **120**, whereupon the drilling mud **150** enters the annulus **115** and circulates drill cuttings away from the drill bit **120**. The movement of drilling mud **150** in the annulus **115** also returns drill cuttings upwardly through the annulus **115**. The drilling mud **150** ultimately returns to the surface and moves through a flow diverter **117** in the rotating control device **142**, through a return conduit **124** and various surge tanks and telemetry receiver systems (not shown separately).

Thereafter the drilling mud **150** proceeds to what is generally referred to herein as a backpressure system **133**. The drilling mud **150** may enter the backpressure system **133** through the return conduit **124** and may pass through a controllable orifice choke **130** and then through a flowmeter **126**. The flowmeter **126** may be a mass-balance type or other high-resolution flowmeter. Using measurements from the flowmeter **126**, a system operator may be able to determine differences between how much drilling mud **150** has been pumped into the well **106** through the drill string **112**, and how much drilling mud **150** returns from the well **106**. Based on any determined differences between the amount of drilling mud **150** pumped into the drill string **112** and the amount of drilling mud **150** returned, the system operator may determine whether drilling mud **150** is being lost to the formation **104**, which may indicate that formation fracturing or breakdown has occurred, i.e., a significant negative fluid differential. Conversely, a determined difference wherein more fluid leaves the well **106** than the amount of drilling mud **150** pumped into the drill string **112** be indicative of formation fluid entering into the well **106** from the formations **104**.

It will be appreciated that there exist chokes designed to operate in an environment where the drilling mud **150** contains substantial amounts of drill cuttings and other solids. The controllable orifice choke **130** may be of a wear resistant type and may be further capable of operating at variable pressures, variable openings or apertures, and through multiple duty cycles. The drilling mud **150** then exits the controllable orifice choke **130**, through the flowmeter **126** and flows through a three way valve **5**. The drilling mud **150** leaving the three way valve **5** for cleaning and return to the reservoir **136** may then be processed by an optional degasser **1** and by a series of filters and a shaker table, shown collectively at **129**, designed to remove contaminants, including drill cuttings, from the drilling mud **150**. The drilling mud **150** is then returned to the reservoir **136**. During "tripping operations", explained further below, the three way valve **5** may be operated to direct fluid from the return conduit **124** to a trip tank fill conduit **4** and thence into a trip tank **2**.

A backpressure system intake conduit **119***a* may have one end disposed in the reservoir **136** and may be selectively placed in fluid communication with one port of a three-way valve **125** for conducting drilling mud **150** to the inlet of a backpressure pump **128**. The inlet of the backpressure pump **128** may be selectively placed in fluid communication with a trip tank **2** using the three way valve **125** connected to the trip tank **2** by a trip tank conduit **119***b*. An outlet of the backpressure pump **128** may be in fluid communication with the return conduit **124** through an isolation valve **123**.

The trip tank **2** is used in a drilling system to monitor drilling fluid gains and losses during tripping operations (withdrawing and inserting the full drill string **112** or substantial subset thereof from the well **106**). The three-way valve **125** may be used to selectively place the inlet of the backpressure pump **128** in fluid communication with the backpressure system intake conduit **119***a*, the trip tank conduit **119***b* or to isolate the backpressure system **133** from fluid communication with any other components. To isolate the backpressure system **133**, the isolation valve **123** may be closed and the three way valve **125** may isolate both the backpressure system intake conduit **119***a* and the trip tank conduit **119***b* from the inlet of the backpressure pump **128**.

In the present example embodiment, the backpressure pump **128** is capable of using returned drilling mud **150** to create a backpressure in the well **106** by operating the three way valve **125** to place the inlet of the backpressure pump **128** in fluid communication with the trip tank conduit **119***b*. It will be appreciated that the returned drilling mud **150** could have contaminants that would not have been removed by the filter/shaker table **129**. In such case, wear on backpressure pump **128** may be increased. To reduce such wear, fluid supply for the backpressure pump **128** may be provided through the backpressure system intake conduit **119***a* from the reservoir **136** to provide reconditioned drilling mud to the inlet of the backpressure pump **128**.

The three-way valve **125** maybe operated to selectively couple the inlet of the backpressure pump **128** to either the backpressure system intake conduit **119***a* or the trip tank conduit **119***b*. The backpressure pump **128** may then be operated to ensure sufficient flow passes through the controllable orifice choke **130** and thence into the well **106** through the return conduit **124** to be able to maintain a selected fluid pressure in the annulus **115**, even when there is no drilling mud **150** being pumped into the drill string **112**. In particular, during tripping operations, as the drill string **112** is withdrawn from the well **106**, the volume of drilling mud **150** in the well **106** displaced by the drill string **112** is reduced. Such reduction in displaced volume will result in reduction of fluid pressure in the well **106**. One function of the backpressure system **133**, among others, is to maintain the fluid pressure in the well **106** during tripping operations.

The well drilling system **100** may include a flow meter **152** in conduit **100** to measure the amount of drilling mud **150** being pumped into the drill string **112**. It will be appreciated that by monitoring the flow meters **126**, **152** and thus the volume pumped by the backpressure pump **128**, it is possible to determine the amount of drilling mud **150** being lost to the formation, or conversely, the amount of formation fluid entering to the borehole **106**. In some embodiments, fluid pressure in the well **106** may be determined by measuring pressure in the return conduit **124**, e.g., by using a pressure sensor **121** in fluid communication with the return conduit **124**.

Operation of the three way valve **125**, the back pressure pump **128**, the controllable orifice choke **130**, the isolation valve **123** and three way valve **5** may be effected by a controller **160**. The controller **160** may be a programmable logic controller (PLC), a microprocessor or any similar device which may accept as input signals from the pressure sensor **121**, the flowmeters **126**, **152** and, e.g., a stroke counter (not shown) on the rig mud pumps **138** to operate the three way valve **125**, the back pressure pump **128**, the controllable orifice choke **130**, the isolation valve **123** and three way valve **5** to maintain a selected fluid pressure in the well **106**.

Having explained an example embodiment of a well drilling system including a backpressure system, an example embodiment of the backpressure pump **128** will be explained with reference to FIG. **2**. The backpressure pump **128** may be a vertically oriented, linear motion pump. The backpressure pump **128** may include a linear motor **201** which operates a connecting rod **204** longitudinally in a reciprocating motion. In the present example embodiment, the linear motor **201** may be a reciprocating hydraulic actuator. The reciprocating hydraulic actuator may comprise an hydraulic cylinder **200** which may be divided into two fluid chambers **200**A, **200**B separated by a fluid barrier **206**, such as a piston. The fluid barrier **206** converts fluid movement into one of the pumping chambers **200**A, **200**B and discharge of fluid from the other one of the pumping chambers **200**B, **200**A into a mechanical output of the linear motor. The fluid barrier **206** may be functionally coupled to the connecting rod **204** such that pumping fluid, such as hydraulic oil into one fluid chamber **200**A causes movement of the fluid barrier **206** in one direction (and corresponding movement of the connecting rod **204**) and causes the fluid to be discharged from the other fluid chamber **200**B. Pumping fluid into the other fluid chamber **200**B will cause opposite operation of the linear motor **201**.

The fluid may be supplied under pressure by an hydraulic fluid pump **210**. An outlet and an inlet of the hydraulic fluid pump **210** may be in fluid communication with a proportional output solenoid valve **212**. The proportional output solenoid valve **212** may have inlet and outlet ports configured to direct a selected fractional amount of the fluid output from the hydraulic pump **210** to one of two fluid lines **214**, **216** depending on the direction in which the fluid barrier **206** is to be moved. The proportional output solenoid valve **212** may also effect fluid communication between one of the fluid lines **214**, **216** from which hydraulic fluid is to be directed to the inlet of the hydraulic fluid pump **210**. Thus, movement of the fluid barrier **206** may be assisted by having suction from the inlet of hydraulic fluid pump **210** in fluid communication with the one of the fluid chambers **200**A, **200**B that is decreasing in volume with movement of the fluid barrier **206**. As movement of the fluid barrier **206** displaces fluid from the corresponding one of the fluid chambers **200**A, **200**B. A proximity sensor **202**, such as a magnetic field sensor, may be placed proximate each longitudinal end of the linear motor **201** such that movement of the fluid barrier **206** to a position proximate each longitudinal end of the linear motor **201** will be detected and communicated to a motor controller **215**. In the event the fluid barrier **206** is moved proximate either longitudinal end of the linear motor **201**, signals from the respective proximity detector **202** may be communicated to the motor controller **215** such that the proportional output solenoid valve **212** may be operated to reverse direction of motion of the fluid barrier **206** and thus the connecting rod **204**.

The embodiment of a linear motor shown in FIG. **2** is only meant to serve as an example of linear motors that may be used with a backpressure pump in accordance with the present disclosure. Other embodiments of a linear motor may include, without limitation, a multiphase AC linear motor having multiphase stator windings and an armature connected to the connecting rod **204**. Other embodiments of a linear motor may include an electric, pneumatic or hydraulic rotary motor having an output shaft coupled to a worm gear, and wherein a ball nut is coupled to the connecting rod **204**.

In other embodiments, the embodiment of position sensors **202** which are proximity sensors may be substituted by a linear position sensor such as a linear variable differential transformer (LVDT).

In embodiments of a linear motor according to the present disclosure, a rate of movement of the linear motor **201** may be controlled by the motor controller **215** such that a selected fluid flow rate is provided by a fluid pump **218** operated by the connecting rod **204**.

In the present example embodiment, the fluid pump **218** may be disposed proximate the linear motor **201** and may be substantially axially aligned with the linear motor **201**. The fluid pump **218** may comprise an hydraulic cylinder **218**C having therein a movable fluid barrier **222** such as a piston functionally coupled to the connecting rod **204**. The movable fluid barrier **222** divides the hydraulic cylinder **218**C into a first pumping chamber **218**A and a second pumping chamber **218**B. Movement of the connecting rod **204** by the linear motor **201** as explained above causes corresponding movement of the movable fluid barrier **222** in the hydraulic cylinder **218**C to displace fluid from one of the pumping chambers **218**A or **218**B and to cause fluid to move into the other one of the pumping chambers **218**B or **218**A, depending on the direction of motion of the movable fluid barrier **222**. Two, opposed one way valves **220**, for example, passively actuated check valves, may be in fluid communication, respectively with a fluid source, e.g., the three way valve (**125** in FIG. **1**) to provide fluid to enter the respective pumping chamber **218**A or **218**B that is increasing in volume with movement of the movable fluid barrier **222** and to prevent back flow of such fluid to the fluid source from the other pumping chamber **218**B or **218**A. Correspondingly, one way valves **220** may be in fluid communication between each of the pumping chambers **218**A, **218**B to conduct discharge from the one of the pumping chambers **218**A, **218**B that is decreasing in volume as a result of motion of the movable fluid barrier **222** to the isolation valve (**123** in FIG. **1**), while preventing reverse flow of fluid back into the other one of the pumping chambers **218**B, **218**A.

In operation, a signal produced by the pressure sensor (**121** in FIG. **1**) is conducted to the controller (**160** in FIG. **1**). A difference between the pressure measured by the pressure sensor (**160** in FIG. **1**) and a selected well pressure will cause the controller (**160** in FIG. **1**) to generate a control signal proportional to the pressure difference. If the pressure difference is negative, the controller (**160** in FIG. **1**) may communicate a proportional control signal to the proportional output solenoid valve **212** to cause corresponding proportional rate movement of the fluid barrier **206**, and thus movement of the movable fluid barrier. When the selected well pressure is reached, the controller (**160** in FIG. **1**) causes the proportional output solenoid valve **212** to close and correspondingly, the fluid barrier **212** immediately stops moving (zero wind down). Thus the illustrated embodiment of the backpressure pump **128** effectively delivers the precise amount of fluid and pressure required to maintain the well fluid pressure to the selected pressure substantially without any overshoot. Overshoot may cause the controller (**160** in FIG. **1**) to open the variable orifice choke (**126** in FIG. **1**) resulting in well pressure oscillations.

A backpressure pump according to the present disclosure may provide one or more of the following advantages compared to backpressure pumps known prior to the present disclosure:

The size of the backpressure pump is small in comparison to known backpressure pumps, in particular the amount of surface area occupied by the backpressure pump may be minimized by oriented the backpressure pump vertically. The length of conduit required to connect a backpressure pump according to the present disclosure to the well and to the fluid source is minimized. A backpressure pump according to the present disclosure would have suction capacity equal to its discharge capacity, therefore such a pump would not require a pre-charge pump in order to draw fluid over long distances. The power requirement for the linear motor to drive such backpressure pump is minimal. Because a backpressure pump according to the present disclosure few moving parts and operates only when needed, the cost to run and maintain it may be substantially less than known backpressure pumps. The simplicity of the design of the present backpressure pump makes possible repairs at the well location quickly and simply. In the embodiment shown in FIG. **2**, seal rings on the fluid barrier **206** and a seal around the connecting rod **204** where it enters the hydraulic cylinder **218**C are substantially the only items subject to substantial wear during operation of the backpressure pump. The one way valves **220**, proportional output solenoid valve **212**, and proximity sensors **202** are all commercially available items and to not require separate design and manufacturing. The simple design of the hydraulic cylinder **218**C, wherein the one way valves **220** are disposed outside the hydraulic cylinder, requires only the most basic machining in order to build.

While a backpressure pump and well pressure control system have been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the present disclosure. Accordingly, the scope of the invention should be limited only by the attached claims.

What is claimed is:

1. An apparatus comprising:

a linear motor comprising a hydraulic cylinder and a fluid barrier disposed therein, the hydraulic cylinder in selective fluid communication on opposed sides of the fluid barrier with a hydraulic fluid source;

a fluid pump functionally connected to the linear motor, a fluid inlet of the fluid pump in fluid communication with a fluid source, a fluid outlet of the fluid pump in fluid communication with a subsurface well, a fluid return conduit of the subsurface well provided outside the subsurface well;

a pressure sensor in fluid communication with the fluid return conduit such that the pressure sensor is provided outside the subsurface well;

a controller functionally coupled to the linear motor and the pressure sensor, wherein the controller is configured to operate the fluid pump to maintain a selected pressure in the subsurface well; and

a proportional output solenoid valve disposed between the hydraulic fluid source and the opposed sides of the fluid barrier, the proportional output solenoid valve in signal communication with the controller to apply a proportional hydraulic pressure to one side of the fluid barrier related to a difference between a measured well fluid pressure and a selected well fluid pressure.

2. The apparatus of claim **1**, wherein the fluid pump comprises a hydraulic cylinder and a movable fluid barrier, the movable fluid barrier functionally coupled to the linear motor.

3. The apparatus of claim **2**, wherein the fluid pump comprises at least one first one-way valve in fluid communication between the fluid source and a respective fluid chamber defined by the movable fluid barrier in the hydraulic cylinder.

4. The apparatus of claim **3** further comprising a three-way valve in selective fluid communication between a fluid reservoir, the fluid return conduit and the at least one first one-way valve.

5. The apparatus of claim **3**, wherein the fluid pump comprises at least one second one-way valve in fluid communication between the subsurface well and a respective fluid chamber defined by the movable fluid barrier in the hydraulic cylinder.

6. The apparatus of claim **5**, further comprising an isolation valve disposed between the at least one first and one second one-way valves and the subsurface well.

7. The apparatus of claim **1**, the pressure sensor in fluid communication with a fluid outlet of the subsurface well and in signal communication with the controller, the pressure sensor providing a signal corresponding to a fluid pressure in the subsurface well.

8. The apparatus of claim **1**, further comprising a position sensor functionally coupled to the linear motor, the position sensor generating a signal corresponding to a longitudinal position of the linear motor.

9. The apparatus of claim **8**, wherein the position sensor is a proximity sensor disposed proximate each longitudinal end of the linear motor or a linear position sensor.

10. The apparatus of claim **9**, wherein the proximity sensor is a magnetic field sensor and the linear position sensor is a linear variable differential transformer.

11. The apparatus of claim **1**, wherein the linear motor and the fluid pump are arranged substantially vertically and in axial alignment.

12. A method, comprising:

providing the apparatus according to claim **1**;

measuring a fluid pressure in the subsurface well using the pressure sensor of the apparatus provided outside the subsurface well;

operating the linear motor functionally coupled to the fluid pump at a rate related to a difference between the selected well fluid pressure and the measured well fluid pressure; and

stopping operation of the linear motor when the measured well fluid pressure is substantially equal to the selected well fluid pressure.

13. The method of claim **12**, wherein the operating the linear motor comprises moving fluid under pressure into the hydraulic cylinder on one side of the fluid barrier, a rate of the moving fluid under pressure related to the rate of operating the linear motor.

14. The method of claim **12**, further comprising automatically reversing direction of movement of the linear motor when a movable element in the linear motor approaches a longitudinal end of the linear motor.

15. The method of claim **14**, wherein the movable element approaching a longitudinal end of the linear motor comprises measuring proximity of the movable element to the longitudinal end.

16. The method of claim **12**, wherein the fluid pump comprises a hydraulic cylinder and a movable fluid barrier, the movable fluid barrier functionally coupled to the linear motor.

17. The method of claim **16**, further comprising constraining flow of fluid from the fluid source to an interior of the hydraulic cylinder on either side of the movable fluid barrier only to a direction from the fluid source to the interior.

18. The method of claim **16**, further comprising constraining flow of fluid from an interior of the hydraulic cylinder on either side of the movable fluid barrier only to a direction from the interior to the subsurface well.

19. The method of claim **12**, wherein fluid discharge from the subsurface well is sealingly in fluid communication with the fluid outlet of the fluid pump.

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